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13. ABSTRACT (Maximum 200 words)

During the period March 1999 – February 2000 work has continued according to the proposed plan. Advances in research have been made in the following areas:

- Exhaustive search and study of the literature on RTD-FET based circuits and their functionality.
- Development of a SPICE model for the RTD that can be used for realistic simulations of RTD-based CNN circuitry.
- Detailed study of the simple CNN cell circuit that is outlined in the project proposal.
- Advances in the development of circuits that are programmable and fully exploit the capabilities of the RTD.

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Monolithic and Vertical Integration of Resonant Tunneling Diodes and FETs for Cellular Neural Networks

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March 1, 1999 - February 28, 2002

Annual Progress Report

for the period March 1999 - February 2000

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Summary

During the first year of the project, we pursued the following tasks according to the proposed plan:

- Exhaustive search and study of of the literature on RTD-FET based circuits and their functionalities.
- Development of a SPICE model for the RTD which can be used for realistic simulations of RTD-based CNN circuitry.
- Detailed study of the simple CNN cell circuit which is outlined in the project proposal.
- Advances in the development of circuits that are programmable and fully exploit the capabilites of the RTD.

A Simple RTD-Based CNN Cell for Linearly Separable Boolean Functions

Publications: [2, 3]

An extremely simple RTD-FET circuit has been studied and shown to behave like an almost ideal comparator, as required for the class of uncoupled CNNs. A SPICE model was implemented for realistic simulations.

While being extremely compact, this cell lacks programmability, which is a serious disadvantage, but specific applications may not require universal cells. We conclude that with RTDs, when sacrificing generality, extremely compact CNN circuitry can be designed.

The restriction to linearly separable Boolean functions and the fixed parameter set are the main reasons why more complex (and more versatile) circuits will have to be designed and studied. A very promising candidate is the circuit characterized in the next paragraph.

An RTD-Based CNN Cell for Arbitrary Boolean Functions

Publications: [4, 5, 6, 7]

By using the principle of nesting piecewise linear circuits, the so-called *Universal CNN Cells* [4], it is possible to take full advantage of all branches in the I–V characteristics of the RTD. Our proposed circuit (Fig. 1) fully supports recently reported nanotechnologies

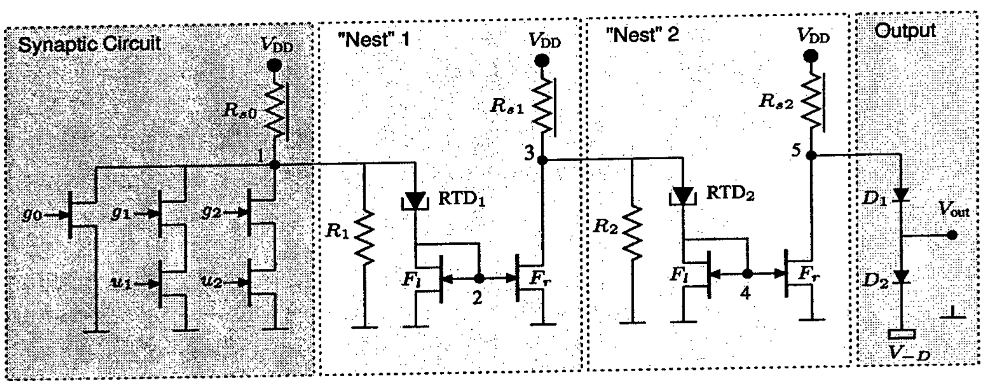

Figure 1: The RTD-CNN cell circuit with 2 inputs and 2 nests.

allowing operation at room temperature and vertical integration of FETs using III-V semiconductors.

Compared to the standard CNN cell [1], the design has several advantages: (a) It uses a simple synapse made of only two n-FET transistors, where the synaptic weights (or CNN templates) are always positive; (b) It expands the domain of realizable Boolean functions beyond the small class of linearly separable Boolean functions, while it uses exactly the same number of parameters to code the template; (c) It targets a promising nanotechnology, from which very high processing speeds and densities are expected.

Simulations in SPICE using realistic device models [7] confirm the theoretical results. The functional capabilities of our cell are indeed impressive.

Outlook

Several important issues will have to be addressed:

- The improvement in terms of speed of the algorithmic method to find Boolean realizations for all possible Boolean functions.
- The optimization of the RTD-CNN circuit for speed, power, and occupied area.
- The development of a new family of RTD-CNN cells, optimized for area but with functional capability limited to linearly separable Boolean functions.
- Extend the RTD SPICE model to include the high-speed *dynamics* of the device.

Publications

[1] L. O. Chua, "CNN: A Vision of Complexity," *International Journal of Bifurcation and Chaos*, vol. 7, pp. 2219–2425, Oct. 1997.

[2] M. Hänggi, L. O. Chua, and R. Dogaru, "A Simple RTD Based Circuit for CNN Cells," in *IEEE International Workshop on Cellular Neural Networks and their Applications*, May 2000. submitted for publication.

[3] M. Hänggi, R. Dogaru, and L. O. Chua, "Physical Modeling of RTD-Based CNN Cells," Memorandum UCB/ERL M00/1, Electronics Research Laboratory, University of California, Berkeley, Jan. 2000.

[4] R. Dogaru and L. O. Chua, "Universal CNN Cells," *International Journal of Bifurcation and Chaos*, vol. 9, pp. 1–48, Jan. 1999.

[5] R. Dogaru, L. O. Chua, and M. Hänggi, "A Compact and Universal RTD-Based CNN Cell: Circuit, Piecewiese-Linear Model, and Functional Capabilities," Memorandum UCB/ERL M99/72, Electronics Research Laboratory, University of California, Berkeley, 1999.

[6] R. Dogaru, L. O. Chua, and M. Hänggi, "A Compact Universal Cellular Neural Network Cell Based on Resonant Tunneling Diodes: Circuit Design, Model, and Functional Capabilites," in *IEEE International Workshop on Cellular Neural Networks and their Applications*, May 2000. submitted for publication.

[7] M. Hänggi, R. Dogaru, and L. O. Chua, "Physical Modeling of RTD Based CNN Cells," in *IEEE International Workshop on Cellular Neural Networks and their Applications*, May 2000. submitted for publication.